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DENVER
AIR POLLUTANT EMISSION
INVENTORY

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A rapid emission inventory of air pollutant sources in the Denver metropolitan area is reported. The objectives were to determine the total quantities of various air pollutants emitted and to estimate their geographical and seasonal variation. The study area was divided into a grid coordinate system and the emission quantities were reported in terms of tons of pollutant per grid on an average annual day, average summer day, and average winter day. Sulfur oxides, particulates, and carbon monoxide were included.

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DENVER AIR POLLUTANT EMISSION INVENTORY

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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AIR POLLUTANT EMISSION INVENTORY

INTRODUCTION

This report presents the results of a rapid emission inventory[1] of air pollutant sources in the Denver metropolitan area. The objectives of this study were to determine the total quantities of various air pollutants emitted and to estimate the geographical and seasonal variation in air pollutant emissions. To accomplish this task, the Study Area was divided into a grid coordinate system and the emission quantities were reported in terms of tons of pollutant per grid on an average annual day, average summer day, and average winter day.

The pollutants considered in this survey are sulfur oxides, particulates, and carbon monoxide. The emissions of other pollutants were not estimated due to a limitation of time, personnel, and available data. Data presented herein are representative of 1967 and were mainly gathered by the acknowledged State and local agencies.

STUDY AREA

The Study Area, as presented in Figure 1, consists of the City and County of Denver, and the Counties of Adams, Arapahoe, Boulder, Jefferson, Larimer, and Weld. This area occupies 10,305 square miles and contains an estimated 1967 population of 1,235,000. Table 1 shows the land areas and the 1960 and 1967 populations for each of the major political jurisdictions.

Approximately 63% of the State population resides in this area which comprises about 10% of the land area of the State. Larimer and Weld Counties are outside the defined boundaries of the Denver Standard

FIGURE 1 - DENVER STUDY AREA

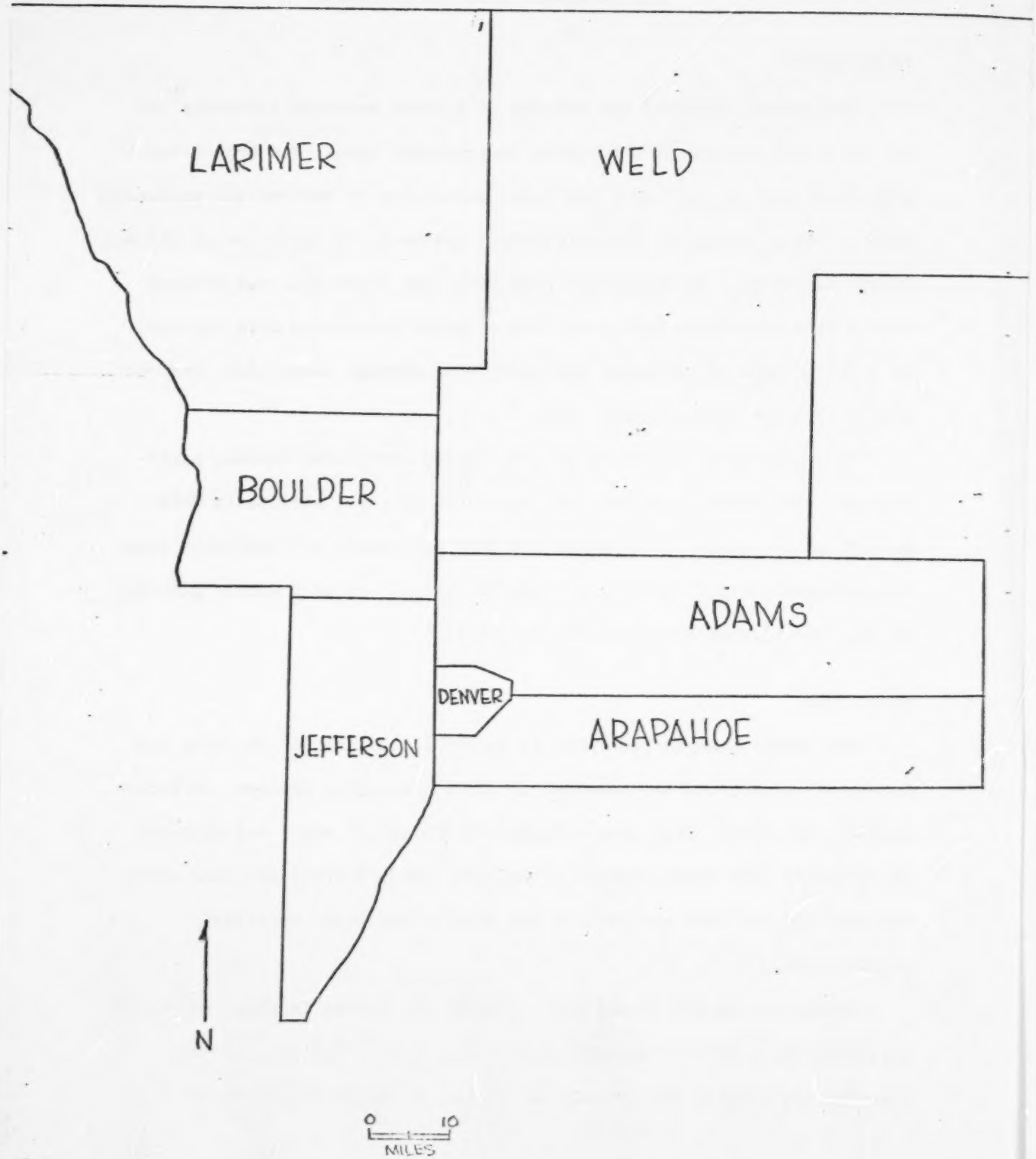


Table 1. DENVER STUDY AREA CHARACTERISTICS[2], 1967

Political Jurisdiction	Land Area (sq. mi.)	Population 1960	Population 1967	Population Density (1967)
Denver SMSA	3,687	929,000	1,083,000	294
Adams County	1,241	120,000	157,000	126
Arapahoe County	801	113,000	131,000	164
Boulder County	758	74,000	105,000	139
Denver City & County	98	494,000	485,000	4,950
Jefferson County	789	128,000	205,000	260
Larimer County	2,614	53,000	72,000*	28
Weld County	4,004	72,000	80,000*	20
Total Study Area	10,305	1,054,000	1,235,000	120

* = Estimated

Metropolitan Statistical Area (SMSA); however, their proximity and degree of industrialization necessitated their inclusion within the Study Area. The Colorado Springs SMSA is located approximately 68 miles South of Denver. Due to the direction of prevailing winds and the sheltering effect of the foothills between the metropolitan areas, Colorado Springs was not included in this study.

Topography

Most of the Study Area is situated east of the foothills of the Rocky Mountains. This area is fairly level with an elevation of 5,000 to 5,500 feet above mean sea level. The foothills are located 18 miles west of Denver and rise from the plateau area to greater than 13,000 feet, in the main ranges, along the western extremities of the Study Area. Denver, itself, is approximately 40 miles east of the main range of the Rocky Mountains[3].

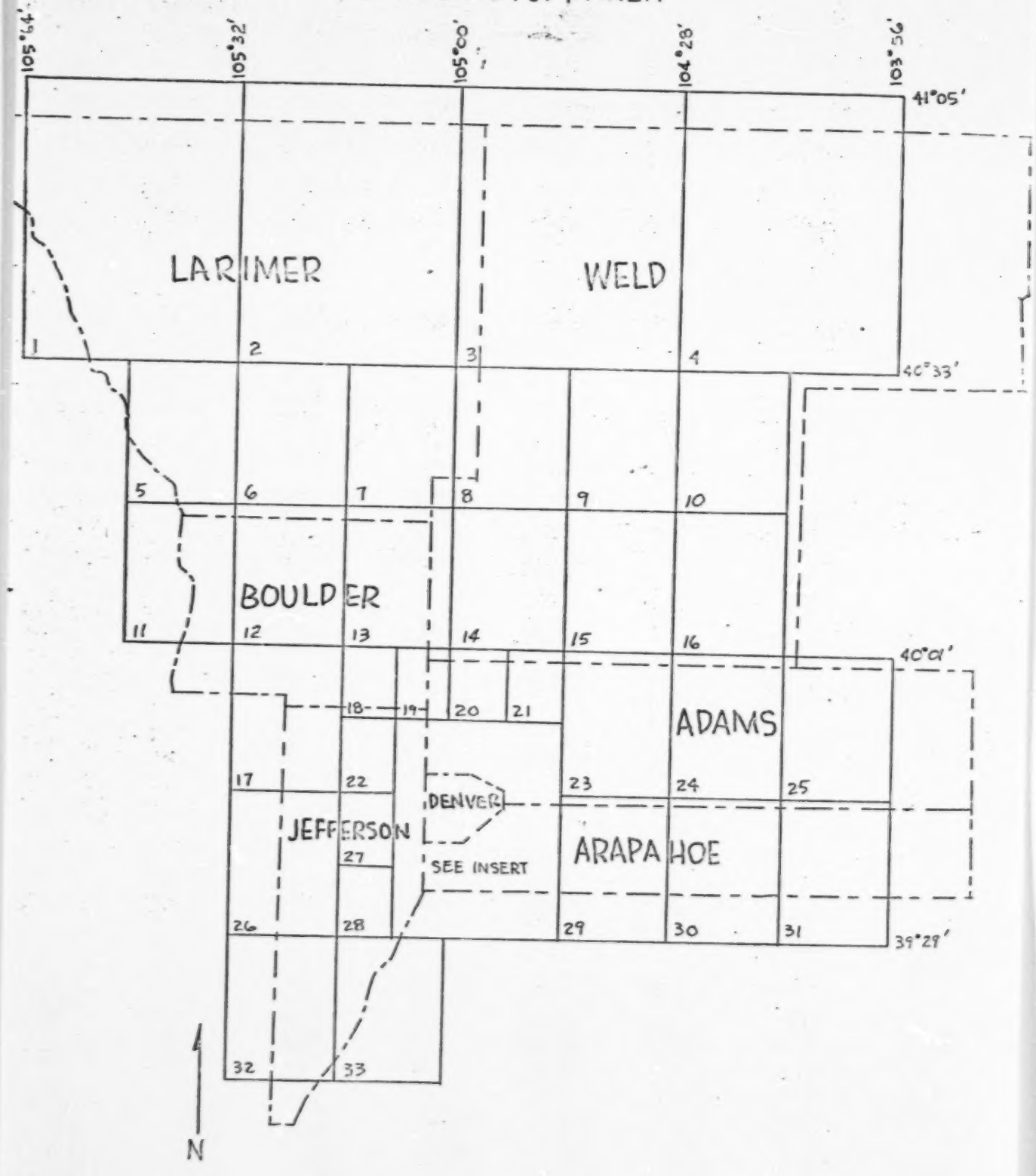
Grid Coordinate System

For the purposes of this survey, the Study Area was divided into 81 grids based on latitude and longitude. Five grid sizes of 2 minute, 4 minute, 8 minute, 16 minute, and 32 minute grids were utilized depending upon the extent of urbanization of the area. Figure 2 indicates the grid system used for reporting the emissions. In those cases where sections of outlying counties are omitted, the air pollutant emissions are considered negligible.

SUMMARY OF RESULTS

The estimated annual emissions of the three surveyed pollutants, in the Study Area, are 31,400 tons of sulfur oxides, 33,400 tons of particulates,

FIGURE 2 - REPORTING ZONES FOR DENVER STUDY AREA



and 616,000 tons of carbon monoxide. The air pollutant emissions by political jurisdiction are indicated in Table 2. Denver has the highest emission rate of particulates and carbon monoxide, and Adams County the highest emission rate of sulfur oxides.

Table 3 lists the breakdown of pollutant emissions by source category in the Study Area. The following is a brief summary of pollutant emissions and sources:

(1) Of the 31,400 tons of SO_x emitted annually, 67% originate from fuel combustion sources, 28% from industrial process losses, and 5% from mobile sources. The contribution from solid waste disposal is negligible. The combustion of coal, mainly in steam electric power plants, produces 62% of the total sulfur oxides in the area.

(2) Particulate emissions from fuel combustion contribute 54%, solid waste disposal 4%, industrial process losses 27%, and mobile sources 15% of the 33,400 tons of particulates emitted in the Study Area. The combustion of coal produces 50% of the total particulate emissions.

(3) Mobile sources contribute 94% of the 616,000 tons of CO emitted per year. Other sources are the combustion of fuels in stationary sources which contribute less than 1%, solid waste disposal 1%, and industrial process losses 4%.

EMISSIONS BY CATEGORY

For purposes of compiling the basic data and emission estimates, the air pollutant sources were classified into the following four categories:

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Table 2. EMISSIONS BY POLITICAL JURISDICTION
(tons/year)

County	SO_x	Part.	CO
Adams	15,100	8,980	94,300
Arapahoe	320	1,180	81,700
Boulder	5,630	4,550	33,600
Denver	6,950	9,370	241,600
Jefferson	1,350	4,670	115,700
SMSA Total	29,400	28,800	567,000
Larimer	910	2,000	22,200
Weld	1,070	2,600	26,400
Study Area Total	31,400	33,400	616,000

Table 3. EMISSIONS BY SOURCE CATEGORY IN STUDY AREA, 1967
(tons/year)

Source category	SO_x	Part.	CO
Fuel combustion (Stationary sources)			
Coal	19,300	16,700	4,400
Oil	1,000	300	100
Gas	570*	1,200	n
Total	20,900	18,200	4,500
Solid waste disposal			
Open burning	n	100	970
Incineration	n	n	n
On-site			
Backyard	13	550	6,600
Incineration	39	650	2,200
Total	50	1,300	9,800
Industrial process	8,800	8,900	24,700
Mobile sources			
Gasoline combustion	1,000	2,300	563,900
Diesel combustion	500	1,300	800
Railroads	100	300	200
Aircraft	n	1,100	11,500
Total	1,600	5,000	576,000

n = negligible
*550 tons/year due to burning of a surplus stock of mustard gas

(1) Fuel combustion in Stationary Sources

(2) Transportation

(3) Solid - Waste Disposal

(4) Industrial process losses

In the following sections, each of the categories is discussed and a summary of the resulting emissions is presented.

Fuel Combustion in Stationary Sources

Although all of the three major fuels are consumed within the Study Area, natural gas is by far the most important. In 1967, natural gas accounted for 110×10^{12} BTUs or approximately 63 percent of the total energy input. As shown in Table 4, approximately 2,330,000 tons of coal, 210,000 barrels of residual fuel oil, 350,000 barrels of distillate fuel oil and 131.2 billion cubic feet of natural gas were consumed in the Study Area. Whereas the coal and natural gas consumption data are fairly accurate, the fuel oil data is a rough estimate, based partially on 1962 data[4,5]. Much of the difficulty with respect to defining fuel oil use data is due to the fact that oil, especially residual fuel oil, is used as standby fuel for interruptible gas consumers. Because of variability in climatic conditions, the annual consumption of fuel oil may therefore vary significantly from one year to the next.

The sulfur and ash contents of the fuels used in the Study Area are summarized in Table 5. The sulfur contents of both coal and fuel oil are relatively low.

There are five steam - electric generating plants within the Study Area. Fuel combustion for each of these is summarized in Table 6. These plants used 85% of the total coal consumed in the Study Area. All of the

Table 4. FUEL CONSUMPTION IN STUDY AREA, 1967

	Coal (1,000 tons)	Fuel Oil		Natural Gas (10^6 cu. ft.)
		Residual (1,000 bbl.)	Distillate (1,000 bbl.)	
Steam-electric utilities	1,973	25	-	16,248
Industry	229	160	58	27,677
Residential	20	-	270	53,559
Commercial-institutional	110	25	22	33,745
Total	2,332	210	350	131,229

Table 5. SULFUR AND ASH CONTENT OF FUELS*, 1967

Fuel	% Sulfur	% Ash
Coal	0.6	6.0
Residual Fuel Oil	0.7	-
Distillate Fuel Oil	0.3	-
Natural Gas	0.0008	-

*Information gathered from local officials and fuel companies.

Table 6. FUEL CONSUMPTION IN STEAM ELECTRIC GENERATING PLANTS,[6,7] 1967

	Coal (tons)	Fuel Oil (barrels)	Gas (mill. cu. ft.)
1. Arapahoe (City of Denver)	233,600[a]	---	9,607
2. Zuni (City of Denver)	134,300[b]	24,700	6,427
3. Cherokee (Adams County)	1,034,000[c]	---	---
4. Valmont (Boulder County)	558,000[d]	---	---
5. Ft. Collins (Larimer County)	13,000[e]	---	214
Total	1,972,900	24,700	16,248

[a]Equipped with cyclones and ESP.

[b]Equipped with cyclones and ESP.

[c]Equipped with ESP.

[d]Equipped with cyclone and ESP.

[e]No control.

plants except Ft. Collins are equipped with some form of air pollution control device.

The primary fuel used by industry is natural gas. Except for a few large consumers of coal and fuel oil, these fuels are used primarily for standby purposes. Six plants collectively consumed over 170,000 tons of coal or 74% of the total coal used in all industrial operations. Fuel use in the commercial and institutional category is not well defined. Here again, interruptible gas supplemented by fuel oil-residual and distillate is used. The largest known users of the heavy fuels are public schools (4,000 tons of coal), Lowry Air Force Base (14,000 tons of coal) and the Federal Center (24,000 tons of coal).

Close to 100 percent of the residences in the urbanized portion of the Study Area are served by natural gas. The outlying areas as well as major housing developments throughout the Area are partially heated by distillate fuel oil and to lesser extent - by coal. An estimated 270,000 barrels of fuel oil and 20,000 tons of coal are used for these purposes.

Emissions from Fuel Combustion

The air pollutant emissions resulting from fuel combustion in stationary sources are listed in Table 7. The emissions are presented for industrial, commercial and institutional, residential, and steam-electric utility sources.

Although the combustion of coal accounts for 35% of the BTU comsumption within the Study Area, coal contributes 94% of the SO_x, 92% of the particulates, and 98% of the CO resulting from the combustion of fuels. The majority of these emissions are isolated in a few large fuel consumers such as power plants, large industries and institutions.

Table 7. AIR POLLUTANT EMISSIONS FROM COMBUSTION OF FUELS IN THE STUDY AREA (tons/yr.)

Fuel	User Category	Pollutant Emissions SO_x	Part.	CO
Coal	Industrial	2,770	5,670	380
	Commercial & Institutional	1,140	4,370	2,760
	Residential	430	820	1,020
	Steam-Electric Utilities	15,000	5,810	210
Fuel Oil	Industrial	500	170	115
	Commercial & Institutional	230	70	3
	Residential	230	60	10
	Power	55	5	neg.
Natural Gas	Industrial	7	250	7
	Commercial & Institutional	555*	320	neg.
	Residential	9	460	9
	Power	neg.	120	neg.

*550 tons SO_x/yr. due to burning of mustard gas.

The combustion of fuels, mainly coal, in the five steam-electric utilities accounts for 48% of the SO_x and 17% of the particulates generated in the Study Area. The particulate contribution is low since the majority of the plants have electrostatic precipitators.

The emissions resulting from the combustion of fuel oil and natural gas are minor compared to that from coal combustion. A unique problem is the 550 tons per year of sulfur oxides resulting from the burning of surplus mustard gas at one of the federal facilities in Adams County.

Data Sources

The natural gas consumption data by consumer category was provided by the Public Service Company of Colorado. Fuel consumption by each of their four steam-electric utility plants in the Study Area was also provided; consumption for the Fort Collins plant, operated by the Fort Collins Light & Power Department, was obtained from "Steam Electric Plant Factors."[7]

Coal consumption by industrial, residential, and commercial-institutional sources was established on the basis of information gathered from local coal dealers[8]. The major consumers of coal had been previously contacted individually by local agencies.

Fuel oil consumption data for industrial establishments were obtained from "Distillate and Residual Fuel Oil Consumed in Manufacturing Industries: 1962"[5]. Fuel oil consumed by residential units in the Study Area was assumed to be only distillate. Dwelling unit data (1960) and type of heating equipment were utilized to calculate fuel oil consumption.[1,9] Commercial and institutional sources of fuel oil were obtained from the major users, and estimated for those users for which data was not available.

Transportation

Three types of transportation sources of air pollution are considered in this survey - motor vehicles, aircraft, and railroads. The emissions caused by the operation of motor vehicles is further subdivided according to type of fuel - gasoline or diesel.

Motor Vehicles

On the basis of gasoline sales data, it is estimated that approximately 475 million gallons of gasoline[10,11] were sold in the Study Area during 1967. Gasoline sales and automobile registrations by major political subdivisions are presented in Table 8. The total of 475 million gallons includes both highway and non-highway uses. Because the non-highway uses account for only 5 to 7 percent, they were considered together with the highway uses.

Approximately 1.5 to 2.0 percent of gasoline is lost through evaporation resulting in annual losses of about 9.5 million gallons. The consumption of gasoline by political subdivisions is presented in Table 9. The apportionment of gasoline consumption was accomplished on the basis of traffic information (vehicle miles) obtained from the Colorado State Department of Highways.[12]

An estimated 24.5 million gallons of diesel fuel is burned by buses and trucks, operating or passing through the Study Area. This accounts for approximately 40 percent of the total amount of diesel fuel consumed in the State of Colorado. The overall estimate as well as the apportionment by counties is based on registration data[12] of diesel powered vehicles in these areas.

Aircraft

Stapleton Airport in the City of Denver, Broomfield Airport in

Table 8. AUTOMOBILE REGISTRATION AND GASOLINE SALES IN DENVER STUDY AREA, 1967

	Automobile Registration (1,000's)	Gasoline Sales (in million gal.)
City of Denver	230.6	403.7
Adams County	78.6	
Arapahoe County	73.0	
Jefferson County	106.9	
Boulder County	53.6	30.7
Larimer County	35.4	20.2
Weld County	36.3	20.8
Total	614.4	475.4

Table 9. CONSUMPTION OF MOTOR FUEL IN THE DENVER STUDY AREA, 1967 (millions of gallons)

Political subdivision	Gasoline consumption	Diesel fuel consumption
City of Denver	205.3	5.8
Adams County		3.4
inside*	45.4	
outside*	6.8	
Arapahoe County		1.8
inside	41.9	
outside	16.7	
Jefferson County		3.0
inside	55.9	
outside	23.6	
Boulder County	30.1	1.9
Larimer County	19.8	2.2
Weld County	20.4	6.4
Total	465.9	24.5

*Refers to portion of county covered by transportation study.

Jefferson County, and the Buckley Air National Guard Field in Arapahoe County are the three major airports in the Study Area. The air traffic activity by type of operation at both of these locations is summarized in Table 10. Collectively, a total of 742,000 operations (take off and landing) were performed during 1967. According to local FAA representatives, about 70% of air carrier flights and 50 percent of the military flights were due to jet powered aircraft.

Railroads

Railroads consume about 5.5 million gallons of diesel oil annually within the Denver area. This value was derived from an estimate made in 1962[3].

Emissions from Transportation Sources

Mobile sources account for 1,600 tons of SO_x, 5,000 tons of Particulates, and 576,000 tons of CO in the Study Area. Approximately 94% of the sulfur oxides, 72% of the particulates, and 98% of the CO from mobile sources are attributed to motor vehicles. As shown in Table 11, the largest concentration of pollutants is located in the counties surrounding Denver and the least concentration in the outlying jurisdictions.

Gasoline powered automobiles and trucks collectively account for 67%, 64%, and 99% respectively, of the 1,500 tons of SO_x, 2,600 tons of Particulates, and 576,000 tons of CO emitted annually by motor vehicles. The remainder is attributed to diesel powered trucks and buses.

The emissions from railroads in the Denver area are negligible. Most of these emissions are concentrated along the South Platte River.

Aircraft activities account for more than 1,100 tons of particulates and 11,500 tons of CO annually in the Study Area. Sulfur oxide emissions are negligible. Stapleton Airport, which is the busiest of the three,

Table 10. AIR TRAFFIC ACTIVITY AT STAPLETON, BROOMFIELD, AND BUCKLEY AIRPORTS CALENDAR YEAR 1967

	Category of Operation	Itinerant Operations	Local Operations
Stapleton (Denver)	Air Carrier	129,141	None
	General Aviation	222,904	90,307
	Military	1,598	960
	Total	353,643	91,267
Broomfield (Jefferson County)	Air Carrier	None	None
	General Aviation	76,111	180,586
	Military	207	58
	Total	76,318	180,644
Buckley (Arapahoe)	Military	(39,596)	

Table 11. AIR POLLUTANT EMISSIONS FROM TRANSPORTATION SOURCES, 1967 (tons/year)

Political jurisdiction	Category	SO_x	Part.	CO
Adams	Motor vehicles-gasoline	125	290	69,600
	Motor vehicles-diesel	70	190	100
	Railroads	40	100	60
	Aircraft	-	-	-
	Total	235	580	69,800
Arapahoe	Motor vehicles-gasoline	140	330	80,200
	Motor vehicles-diesel	35	100	55
	Railroads	10	27	15
	Aircraft	n	220	1,170
	Total	185	680	81,400
Boulder	Motor vehicles-gasoline	75	175	32,600
	Motor vehicles-diesel	40	105	60
	Railroads	6	15	8
	Aircraft	n^a	n^a	n^a
	Total	120	300	32,670
Denver	Motor vehicles-gasoline	365	825	228,000
	Motor vehicles-diesel	115	320	175
	Railroads	40	100	60
	Aircraft	n	880	9,550
	Total	520	2,125	237,800
Jefferson	Motor vehicles-gasoline	200	450	113,400
	Motor vehicles-diesel	60	175	90
	Railroads	14	40	20
	Aircraft	n	20	800
	Total	275	685	114,300
Larimer	Motor vehicles-gasoline	46	110	20,700
	Motor vehicles-diesel	45	120	65
	Railroads	n^a	n^a	n^a
	Aircraft	n^a	n^a	n^a
	Total	90	230	20,800
Weld	Motor vehicles-gasoline	43	105	19,400
	Motor vehicles-diesel	130	355	195
	Railroads	n^a	n^a	n^a
	Aircraft	n^a	n^a	n^a
	Total	170	460	19,600
Grand total		1,600	5,000	576,000

n=negligible

n^a = not available

contributes 80% of the particulates and 83% of the carbon monoxide from aircraft operations.

Solid - Waste Disposal

Approximately one million tons of combustible refuse are generated annually within the Denver Study Area. The bulk of this refuse is collected and disposed of by means of modified sanitary land fills, which rarely become a source of air pollution. According to a survey conducted by the U.S. Public Health Service in 1967[13], about 870,000 tons or almost 90 percent, are disposed of in this manner. The remainder, as shown in Table 12, is either composted, incinerated, or burned openly in dumps and on-site. There are no municipal incinerators in the Study Area. Open burning is prevalent only in the two rural counties - Larimer and Weld, where some 80,000 tons of refuse are burned annually.

There are no major individual sources of refuse burning in the Study Area. The burning of refuse in dumps is spread amoung 20 locations with yearly burning ranging from 30 tons to 3,000 tons. These, although not considered as point sources, were identified and located within the grid system.

The burning of automobile components has been a localized nuisance in the past. This practice is presently banned and is no longer a problem in the Study Area.

Emissions from Solid - Waste Disposal

A total of 50 tons of SO_x, 1,300 tons of particulates, and 9,800 tons of CO are emitted annually from solid waste disposal practices. The breakdown of emissions is presented in Table 13. The majority of emissions are due to on-site incineration and backyard burning of refuse in Denver and

Table 12. REFUSE DISPOSAL IN DENVER STUDY AREA, 1967 (tons/year)

Political Subdivision	Combustible Refuse Generated	Incineration		Landfills	Open-Burning	
		Municipal	On-Site		Dumps	On-Site
Denver City	398,000	---	12,000	386,000	---	---
Adams County	129,000	---	n*	123,000	6,000	---
Arapahoe County	108,000	---	n*	107,000	1,000	---
Boulder County	86,000	---	600	52,000	---	---
Jefferson County	168,000	---	7,800	160,000	400	---
Larimer County	59,000	---	n*	43,000	8,700	7,100
Weld County	65,000	---	n*	1,500	n*	64,000
Total	1,013,000	---	20,400	872,500	16,100	71,100

*Negligible

Table 13. AIR POLLUTANT EMISSIONS FROM SOLID WASTE DISPOSAL - 1967 (tons/yr)

Jurisdiction	Type of Disposal	SO_x	Part.	CO
Adams	Open Burning	n*	45	240
	Incineration	n	n	n
	On-site			
	Backyard	n	n	n
	Incineration	n	37	n
	Total	n	80	240
Arapahoe	Open Burning	n	2	9
	Incineration	n	n	n
	On-site			
	Backyard	n	n	n
	Incineration	n	n	n
	Total	n	2	9
Boulder	Open Burning	n	n	n
	Incineration	n	n	n
	On-site			
	Backyard	n	n	n
	Incineration	n	5	60
	Total	n	5	60
Denver	Open Burning	n	n	n
	Incineration	n	n	n
	On-site			
	Backyard	n	n	n
	Incineration	36	590	1,970
	Total	36	590	1,970
Jefferson	Open Burning	n	3	15
	Incineration	n	n	n
	On-site			
	Backyard	n	n	n
	Incineration	n	16	207
	Total	n	16	220
Larimer	Open Burning	n	53	710
	Incineration	n	n	n
	On-site			
	Backyard	n	70	265
	Incineration	n	n	n
	Total	n	120	980
Weld	Open Burning	n	n	n
	Incineration	n	n	n
	On-site			
	Backyard	13	477	6,350
	Incineration	n	n	n
	Total	13	480	6,350
Grand Total		50	1,300	9,800

N* - negligible

Weld Counties. The remainder is divided among open dumps that are burned intermittently, and onsite disposal sites in the other counties.

Industrial Process Losses

Table 14 presents the number and type of selected manufacturing establishments in the Study Area. Although the Study Area is notably void of any large heavy industrial complexes, it does contain a significant number of industries that generate air pollution emissions from their processes. These include some 30 foundries, a cement plant, 2 refineries, 10 asphalt batching and roofing plants, 6 sand and gravel operations, 13 grain storage and processing facilities, a sulfuric acid manufacturing plant, 6 sugar producing plants and a number of miscellaneous operations. Where adequate information was available, emission estimates were made and are included in this survey. As is the case in any emission inventory, the lack of emission factors[15] for some industrial processes did not allow a complete estimation of process emissions.

There are 14 iron and steel foundries and 16 non-ferrous foundries operating in the Study Area. Based on a 5-day week, an estimated 500 tons of metal per day are produced in the ferrous foundries. The distribution of production by type of furnace and air pollution control equipment is summarized in Table 15.

Seven asphalt batching plants produce approximately 890,000 tons of asphalt per year. The plants range in size from 50,000 to 400,000 tons per year. All of the plants are equipped with air pollution control devices, primarily cyclone separators and scrubbers. Three asphalt roofing plants have a collective production rate of 37,000 tons per year. The two largest plants (31,000 tons per year) are equipped with scrubbers, whereas the

Table 14. SELECTED MANUFACTURING ESTABLISHMENTS[14] IN THE DENVER STUDY AREA, 1966

Type of Establishment	Number
Fabricated Structural & Metal Products	170
Miscellaneous Machinery	280
Textiles	100
Concrete, Gypsum, & Clay Products	110
Instrument Manufacture	68
Food & Kindred Products	215
Chemicals	58
Paper Products	36
Glass Products	22
Roofing & Paving	9
Stone Products	16
Paint Manufacture	12
Printing & Coating	280
Wood Products, Furniture	160
Miscellaneous Manufacturing	180

Table 15. PRODUCTION AND EQUIPMENT IN FERROUS FOUNDRIES, 1967

Furnace Type	Number	Production Rate (tons/day)	Air Pollution Control Equipment
Electric arc	4	66	all equipped w/baghouse
Open hearth	1	2	N. A.
Induction	9	270	no controls
Elec. induction	1	31	N. A.
Cupola	1	80	baghouse & afterburner
	3	40	no controls
Other	3	6	no controls
Total	22	495	

smallest is uncontrolled.

A portland cement plant located in Larimer County produces 1,430 tons of cement per day by the dry process. The rotary driers are equipped with fabric baghouses and the clinker kilns are equipped with cyclones and electrostatic precipitators.

Six sand and gravel operations produce a total of 1,300 tons of aggregate per day. Much of the crushing, screening and handling activities are controlled by baghouse and cyclone collectors.

Two petroleum refineries and a small re-refining operation are located in Adams County. The two refineries have a collective throughput rate of 33,000 barrels per day of sweet crude and 3,500 barrels per day of asphalt crude. The sulfur content of the crude oil is approximately 0.3%. The operation at both of these plants includes vacuum distillation, catalytic cracking, and reforming. The combined catalytic cracking rate is about 14,800 barrels per day fresh feed. One of these uses a Thermofor unit whereas the other employs a fluid catalytic cracker.

The Denver Metropolitan Area is a major grain handling, processing and storage center. There are 13 major grain handling and storage establishments located in the Study Area. In addition to handling and storing, five of these establishments have milling facilities. Table 16 presents the annual storage as well as milling capacities by type of grain. More than 50 million bushels of grain, primarily corn, milo and wheat, were handled during 1967. An estimated 310,000 tons of wheat were milled in the Denver area during 1967.

There is a variety of chemical plants in the Study Area. Among these are producers of sulfuric acid, ammonium sulfate, phosphate and nitrate fertilizers, and others. A chemical plant located within the City of Denver

Table 16. STORAGE AND MILLING OF GRAIN IN THE STUDY AREA, 1967

Type	Storage Capacity (million bu/year)	Milling (10^3 tons/year)
Corn	18.0	---
Milo	18.0	---
Wheat	10.4	310.0
Barley	1.6	---
Oats	0.3	---
Rice	1.0	---
Rye	1.0	---
Alfalfa	---	7.5
Total	50.3	317.5

produces 100 tons/day of sulfuric acid, 20-30 tons per day of aluminum sulfate and 10-15 tons per day of nitric acid. A fertilizer plant in Boulder operates for a period of 4 months producing 50 tons per day.

Among the other types of industries located in the Study Area are six beet sugar plants, several lumber and paperboard mills, and numerous fabricated metal shops. The six beet sugar plants located in Adams, Larimer, and Weld Counties process more than 8,500 tons per day during seasonal peak.

There are numerous establishments in the Study Area that manufacture or utilize organic solvents in their operations. These include dry cleaning plants, paint shops, wood preservative operations, and printing and publishing establishments. The hydrocarbons generated by these establishments have not been included in this study.

Emissions from Industrial Process Losses

Air pollutants from industrial process losses account for 8,800 tons of the SO_x, 8,900 tons of the particulates, and 24,700 tons of the CO emitted annually in the Study Area. The breakdown of emissions by industry types is shown in Table 17.

The two petroleum refineries in the Study Area generate 77% of the sulfur oxides emitted by process loss sources. Approximately four-fifths of this is due to the burning of plant fuel containing hydrogen sulfide. Two chemical plants producing sulfur and sulfuric acid account for the remainder of the SO_x emissions.

The storage and processing of grain in the Study Area account for 57% of the particulates from process losses. Although most of the plants are equipped with cyclones, fine particles are released into the atmosphere. The remainder of the particulate emissions are divided among the other

Table 17. AIR POLLUTANT EMISSIONS FROM PROCESS LOSS SOURCES IN THE STUDY AREA, 1967 (tons/year)

Type of Industry	SO_x	Part.	CO
Asphalt batching plants	---	80	---
Asphalt roofing plants	---	150	---
Chemical plants	2,000	---	---
Cement manufacturers	---	120	---
Ferrous foundries	---	230	1,280
Grain storage & processing	---	5,060	---
Non-ferrous foundries	---	20	---
Petroleum refining	6,830	260	23,400
Sand & gravel operations	---	1,140	---
Other	---	1,840	---
Total	8,800	8,900	24,700

industries in the Study Area.

The catalytic cracking units in the petroleum refineries produce 95% of the carbon monoxide generated from industrial process losses. Gray iron cupolas in the ferrous foundries account for the remaining 5% of the CO emissions.

EMISSIONS BY GRIDS

For the purpose of modeling the air pollutant emissions in the Study Area, the resulting emissions are apportioned on the grid coordinate system. Sixteen point sources of SO_x, 15 point sources of particulates, and 2 point sources of CO are identified individually with respect to location and emissions. The emissions for SO_x, particulates, and CO are presented in Tables 18A and 18B as average summer day, average winter day, and average annual day estimates.

The daily emission rates were obtained by dividing yearly totals by appropriate operating day values. Fuel combustion was divided into space heating and constant emissions. Space heating was apportioned on the basis of degree day variations. Residential emissions were assumed to occur throughout the year. Unless specific data was obtained from individual sources, industrial, commercial, and institutional sources were assumed to operate from 250 to 310 days per year. Mobile sources and solid waste disposal sources were assumed to be spread thoughout the year. The seasonal variations in motor vehicle emissions were based on average daily traffic factors.

KEY TO EMISSION TABLES

1) Area - Square Kilometers

2) SO_x - Sulfur Oxides

3) Part. - Particulates

4) CO - Carbon Monoxide

5) S - Average Summer Day

6) W - Average Winter Day

7) A - Average Day

Table 18A. SUMMARY OF EMISSIONS FROM AREA SOURCES BY SEASON

Grid	Area Sq.Km.	SO_x Ton/Day S	W	A	Part. Ton/Day S	W	A	CO Ton/Day S	W	A
1	2,741	.0	.0	.0	.01	.01	.01	.69	.57	.61
2	2,741	.47	1.23	.85	2.03	3.88	2.96	44.74	36.56	39.24
3	2,741	.16	.42	.29	.63	.89	.76	12.28	10.52	11.10
4	2,741	.01	.03	.02	.16	.20	.18	3.61	3.03	3.22
5	171.4	.0	.02	.01	.08	.12	.10	1.36	1.11	1.19
6	171.4	.0	.0	.0	.02	.02	.02	1.31	1.06	1.14
7	171.4	.10	.40	.25	.45	1.32	.89	21.27	17.49	18.73
8	171.4	.39	.65	.52	.47	.77	.62	8.25	7.08	7.46
9	171.4	.48	1.33	.91	2.09	4.04	3.07	39.37	33.51	35.43
10	171.4	.08	.08	.08	.08	.08	.08	1.25	1.01	1.09
11	171.4	.0	.02	.01	.04	.08	.06	4.11	3.32	3.58
12	171.4	.47	1.44	.96	1.40	4.38	2.90	51.50	41.67	44.89
13	171.4	.49	1.11	.80	2.23	4.10	3.17	22.11	18.17	19.46
14	171.4	.08	.20	.14	.41	.69	.55	8.57	7.40	7.78
15	171.4	.05	.07	.06	.16	.20	.18	2.67	2.31	2.43
16	171.4	.0	.0	.0	.19	.19	.19	2.24	2.00	2.08
17	171.4	.0	.0	.0	.04	.04	.04	5.31	4.29	4.62
18	42.84	.82	1.24	1.03	1.14	1.38	1.26	29.64	23.97	25.83
19	42.84	.21	.43	.32	.55	1.17	.86	29.75	24.47	26.20
20	42.84	.04	.04	.04	.10	.10	.10	5.77	4.67	5.03
21	42.84	.07	.07	.07	.27	.27	.27	12.68	10.25	11.05
22	42.84	.27	.63	.45	.73	1.92	1.33	49.43	40.01	43.13
23	171.4	.0	.0	.0	.04	.04	.04	.78	.65	.69
24	171.4	.0	.0	.0	.11	.11	.11	1.25	1.12	1.16
25	171.4	.0	.0	.0	.0	.0	.0	.46	.37	.40
26	171.4	.07	.07	.07	.15	.15	.15	23.64	19.09	20.58
27	42.84	.36	.60	.48	.71	1.58	1.15	61.09	49.34	53.19
28	42.84	.04	.04	.04	.08	.08	.08	16.20	13.08	14.10
29	171.4	.0	.0	.0	.04	.04	.04	5.74	4.64	5.00
30	171.4	.0	.0	.0	.04	.04	.04	5.74	4.64	5.00
31	171.4	.0	.0	.0	.05	.05	.05	5.77	4.67	5.03
32	171.4	.01	.01	.01	.04	.04	.04	4.08	3.29	3.55
33	171.4	.0	.0	.0	.01	.01	.01	1.63	1.32	1.42
34	42.84	.05	.05	.05	.10	.10	.10	19.02	15.36	16.56
35	42.84	.12	.16	.14	.27	.43	.35	38.10	30.78	33.18
36	42.84	.14	.18	.16	.95	1.03	.99	44.59	36.01	38.82
37	42.84	.20	.26	.23	.83	.97	.90	33.69	27.27	29.37
38	42.84	.16	.50	.33	.28	1.43	.86	40.37	32.68	35.20
39	10.71	.05	.53	.29	.62	.94	.78	13.58	10.98	11.83
40	10.71	.07	.65	.36	.16	2.17	1.17	20.99	17.01	18.31
41	10.71	.10	.20	.15	.20	.28	.24	12.19	9.85	10.62
42	10.71	.12	.26	.19	.36	.80	.58	59.76	48.31	52.06
43	10.71	.09	.15	.12	1.27	1.41	1.34	15.09	12.19	13.14
44	10.71	.29	.43	.36	3.30	3.66	3.48	50.43	38.98	42.73
45	10.71	.11	.17	.14	1.63	1.77	1.70	15.67	12.77	13.72
46	10.71	.15	.41	.28	3.08	3.91	3.50	59.80	48.35	52.10

(Continuation of Table 18A)

Grid	Area Sq. Km.	SO_x Ton/Day S	W	A	Part. Ton/Day S	W	A	CO Ton/Day S	W	A
47	10.71	.08	.16	.12	.79	1.03	.91	20.70	16.73	18.03
48	10.71	.15	.21	.18	.48	.68	.58	23.94	19.37	20.87
49	10.71	.02	.02	.02	.02	.02	.02	3.73	3.01	3.25
50	10.71	.01	.01	.01	2.45	2.45	2.45	32.06	30.93	31.30
51	171.4	.12	.20	.16	.40	.64	.52	26.12	21.11	22.75
52	42.84	.18	.92	.55	.19	3.15	1.68	33.58	27.27	29.34
53	10.71	.10	.70	.40	.20	2.49	1.35	28.16	22.79	24.55
54	10.71	.05	.23	.14	.10	.64	.37	19.07	15.41	16.61
55	10.71	.09	.31	.20	1.02	1.66	1.34	60.28	48.83	52.58
56	10.71	.08	.20	.14	1.39	1.79	1.59	36.88	29.83	32.14
57	10.71	.31	1.09	.70	.81	3.28	2.05	111.57	90.19	97.19
58	10.71	.21	.39	.30	1.76	2.28	2.02	59.83	48.38	52.13
59	10.71	.13	.55	.34	.33	1.78	1.06	59.77	48.32	52.07
60	10.71	.06	.18	.12	.20	.60	.40	31.90	25.82	27.81
61	10.71	.09	.29	.19	.23	.99	.61	36.89	29.84	32.15
62	10.71	.04	.06	.05	.06	.22	.14	15.79	12.75	13.75
63	10.71	.32	64	.48	.09	.53	.31	19.72	15.94	17.18
64	10.71	.04	.04	.04	.01	.01	.01	3.91	3.15	3.40
65	42.84	.22	.40	.31	.19	.67	.43	37.37	30.19	32.54
66	42.84	.01	.01	.01	.72	.72	.72	23.31	19.44	20.71
67	42.84	.07	.07	.07	.10	.16	.13	16.29	13.16	14.19
68	42.84	.27	.35	.31	.74	1.06	.90	41.77	33.81	36.42
69	42.84	.38	.60	.49	.97	2.02	1.50	53.43	43.18	46.54
70	42.84	.15	.15	.15	.45	.55	.50	31.96	26.63	28.38
71	42.84	.05	.05	.05	.05	.05	.05	13.21	10.67	11.50
72	42.84	.0	.0	.0	.01	.01	.01	2.87	2.32	2.50
73	42.84	.05	.05	.05	.08	.08	.08	16.20	13.08	14.10
74	42.84	.13	.15	.14	.27	.39	.33	19.28	15.57	16.79
75	42.84	.08	.08	.08	.10	.16	.13	16.40	13.25	14.28
76	42.84	.04	.04	.04	.04	.06	.05	9.17	7.40	7.98
77	42.84	.02	.02	.02	.05	.05	.05	4.08	3.29	3.55
78	42.84	n^a	n^a	n^a	n^a	n^a	n^a	n^a	n^a	n^a
79	42.84	n^a	n^a	n^a	n^a	n^a	n^a	n^a	n^a	n^a
80	42.84	n^a	n^a	n^a	n^a	n^a	n^a	n^a	n^a	n^a
81	171.4	.04	.04	.04	.08	.08	.08	14.91	12.04	12.98

n^a = not available (Douglas County)

Table 18B. SUMMARY OF EMISSIONS FROM POINT SOURCES BY SEASON

Type of Plant	Grid	SO_x Ton/Day			Part. Ton/Day			CO Ton/Day		
		S	W	A	S	W	A	S	W	A
Chemical Plant	56	4.49	4.49	4.49	-	-	-	-	-	-
Chemical Plant	58	3.60	3.60	3.60	-	-	-	-	-	-
Industry	22	0.81	1.20	1.01	4.14	5.70	4.90	-	-	-
Grain Elevator	41	-	-	-	7.70	7.70	7.70	-	-	-
Grain Elevator	47	-	-	-	2.42	2.42	2.42	-	-	-
Industry	13	1.94	2.88	2.41	1.81	2.46	2.18	-	-	-
Industry	21	neg.	4.00	1.43	neg.	10.00	3.60	-	-	-
Industry	9	neg.	2.44	0.89	neg.	6.45	2.32	-	-	-
Federal Facility	51	2.20	2.20	2.20	-	-	-	-	-	-
Federal Facility	63	-	-	-	2.11	6.30	4.18	-	-	-
Industry	7	neg.	4.45	1.59	neg.	3.06	1.10	-	-	-
Industry	9	neg.	2.67	0.97	neg.	3.78	1.36	-	-	-
Federal Facility	52	0.05	1.59	0.80	0.19	7.53	3.78	-	-	-
Power Plant	55	1.10	6.20	2.95	0.55	2.15	1.15	-	-	-
Power Plant	68	0.53	8.92	4.88	0.55	3.23	1.95	-	-	-
Power Plant	45	16.80	23.20	21.50	6.03	8.35	7.73	-	-	-
Power Plant	13	11.85	13.50	11.60	4.28	4.88	4.18	-	-	-
Power Plant	2	-	-	-	1.30	1.30	1.30	-	-	-
Refinery	45	16.91	16.91	16.91	-	-	-	27.20	27.20	27.20
Refinery	45	1.80	1.80	1.80	-	-	-	37.00	37.00	37.00

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